Broadband Slot Cut Gap-coupled Proximity fed E-shaped Microstrip Antenna

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ABSTRACT
Bandwidth of proximity fed E-shaped microstrip antenna has been increased by gap-coupling pair of rectangular slot cut rectangular microstrip antennas along its radiating edges. The patch and slot dimensions were optimized to cover 800 – 1200 MHz frequency band. In this paper, a detail analysis to study the effects of slot and patch dimension on the broadband response in desired frequency band for the gap-coupled configuration is presented. The pair of rectangular slots reduces the resonance frequency of orthogonal TM_{02} mode of the parasitic patch and along with the modes of the E-shaped patch yields broadband response. The variation in patch dimension of E-shaped patch increases the resonance frequencies of the modes of E-shaped patch which also optimizes the impedance for the broadband response. The slot also modifies the directions of surface currents at TM_{02} mode and re-orients them along patch length. Thereby it gives broadside radiation pattern over the complete bandwidth

Keywords
Rectangular microstrip antenna, Broadband microstrip antenna, E-shaped microstrip antenna, Rectangular slot, Higher order modes, Proximity feeding

1. INTRODUCTION
The more commonly used techniques to realize broadband microstrip antenna (MSA) is by cutting the slot at an appropriate position inside the patch [1 – 5]. In most of the reported configurations, slot cut MSAs are optimized on air substrate of thickness 0.06 – $0.08\lambda_0$. To realize further increase in bandwidth (BW), these antennas are optimized using substrate of thickness more than $0.08\lambda_0$, in conjunction with the proximity feeding technique [6, 7]. While designing slot cut MSAs in desired frequency band, the slot length is taken equal to either half wave in length (when slot is cut inside the patch) or quarter wave in length (when slot is cut on the edges of the patch). However this simpler approximation of slot length against the wavelength does not give accurate results. The analysis of dual band U-slot cut rectangular MSA (RMSA) has been reported [8]. The resonance frequency equations in terms of slot and patch dimension are given. However, a clear description of the modes at various frequencies in that configuration was not given. An analysis to study the effect of slot on broadband response in slot cut MSAs is reported [9 – 11]. Through the analysis it was observed that the slot does not introduce any additional mode but reduces the resonance frequency of higher order orthogonal mode of the patch and along with the fundamental patch mode yields broadband response. The slot also modifies the surface current distribution at higher order mode and thereby realizes broadside radiation pattern over the complete BW without any variations in the directions of the principle planes. The broadband E-shaped MSA is realized by cutting pair of rectangular slots on the radiating edges of the RMSA [12]. The further increase in BW and gain of E-shaped MSA is realized by gap-coupling parasitic pair of rectangular slot cut RMSAs along the radiating edges of the E-shaped MSA [13]. The patch and slot dimensions were optimize to cover 800 – 1200 MHz frequency band. This configuration yields BW of more than 550 MHz. However which mode in the parasitic RMSA that results in increased BW and the effect of variation in width of E-shaped MSA is not reported.

In this paper, broadband configurations of proximity fed E-shaped MSA and E-shaped MSA gap-coupled to pair of rectangular slot cut RMSAs are discussed. Further to understand the effect of slot in gap-coupled configuration, an analysis of gap-coupled slot cut configuration is presented. The resonance curve plots, surface current distribution and radiation pattern plots generated using IE3D software were studied [14]. The pair of slots reduces the resonance frequency of higher order orthogonal TM_{02} mode of the parasitic RMSA and along with the modes of the E-shaped MSA, realizes broadband response. The slots also modify the directions of surface currents and align them along the horizontal direction inside the patch. Thereby it gives broadside radiation pattern over the complete BW. The patch width in E-shaped MSA is reduced which optimizes the resonance frequency and impedance at its modes to realize larger BW. Thus the proposed study will help in understanding the functioning of slot cut gap-coupled broadband MSAs.

2. PROXIMITY FED BROADBAND E-SHAPED MSAs
The broadband proximity fed E-shaped MSA is shown in Fig. 1(a, b). The MSA is optimized on air substrate of thickness (h) 3.0 cm ($0.09\lambda_0$). It yields simulated and measured BW of more than 350 MHz in 1000 MHz frequency band. To increase the gain, parasitic RMSAs were gap-coupled along the radiating edges of the proximity fed E-shaped MSA as shown in Fig. 1(c) [12]. This configuration realizes BW of more than 450 MHz. To further increase the BW, pair of rectangular slots cut is cut inside the parasitic RMSAs as shown in Fig. 1(d) [12]. To optimize this configuration in 800 – 1200 MHz frequency band, pair of slot lengths and width of proximity fed E-shaped MSA were adjusted. It yields BW of more than 550 MHz with broadside radiation pattern and gain of more than 8 dBi over the BW. However, effects of slot length in parasitic RMSA and variation in width of the E-shaped MSA were not explained [12]. To explain the same, an analysis of slot cut gap-coupled configuration is presented in the following section.

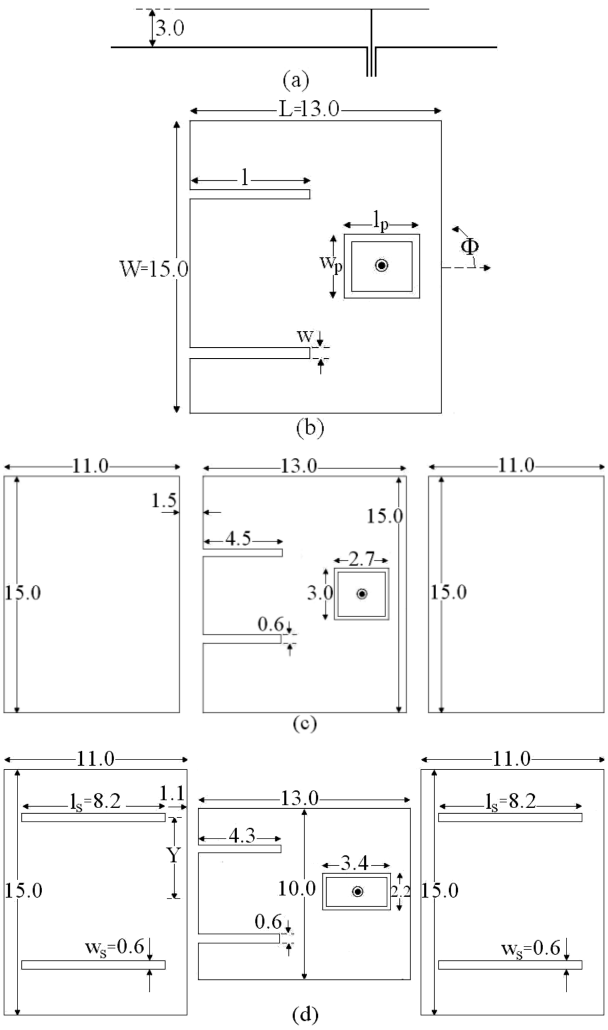


Fig. 1 (a) Top and (b) side views of proximity fed E-shaped MSA, proximity fed E-shaped MSA gap-coupled to (c) RMSA and (d) pair of rectangular slot cut RMSAs

3. ANALYSIS OF PROXIMITY FED GAP-COUPLED E-SHAPED MSA WITH SLOT CUT RMSAs

The proximity fed E-shaped MSA gap-coupled to parasitic RMSA was simulated using IE3D software and its resonance curve plot is shown in Fig. 2(a). The curve shows three peaks at 790, 1073 and 1190 MHz, due to the TM_{10} mode on each of the parasitic RMSAs and the modes of E-shaped patch. The plot shows another peak in the higher frequency region at frequency of 1667 MHz. The surface current distribution at this frequency shows the distribution of modified TM_{21} mode inside the proximity fed E-shaped MSA. The parasitic RMSA dimensions in the optimized gap-coupled configuration are, L = 11.0 cm and W = 15.0 cm. This RMSA was separately simulated using IE3D software and its observed frequency in the resonance curve plots are, 973 MHz (TM_{10}) and 1462 MHz (TM_{02}). In their gap-coupled configuration, since an impedance matching at TM_{02} mode for parasitic RMSA is not realized, a separate peak due to the same is absent in the resonance curve (Fig. 2(a)). For the above isolated parasitic RMSA, radiation pattern at TM_{10} mode is in the broadside direction with E-plane aligned along $\Phi = 0^0$. At TM_{02} mode, the radiation pattern is conical, i.e. maximum in the end-fire direction, with E-plane aligned along $\Phi = 90^0$. Inside this parasitic RMSA, slot of dimension l_s and w_s is cut as shown in Fig. 1(d). For Y = 4.0 cm, the resonance curve plots for varying slot lengths are shown in Fig. 2(b). With an increase in slot length, TM_{02} mode frequency reduces as the surface currents at that mode are orthogonal to the slot length and further it comes closer to TM_{10} mode. The surface current distributions at TM_{02} mode without the slot and for slot length of 8.0 cm are shown in Fig. 3(a, b). With an increase in slot length, more and more amount of surface currents is getting aligned along the horizontal direction inside the patch. This changes the E-plane direction to $\Phi = 0^0$ as shown in Fig. 3(c, d) for two different slot lengths.

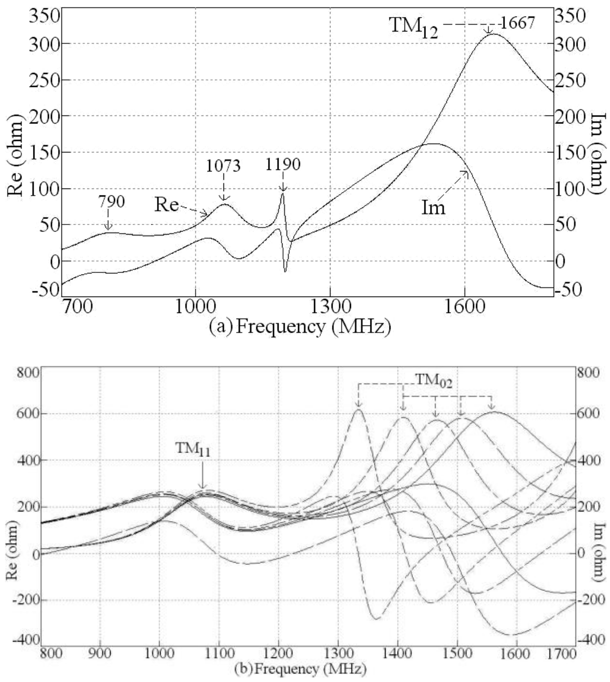
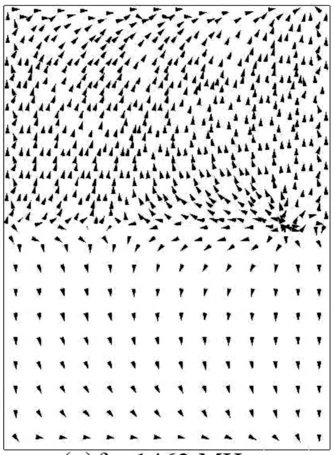
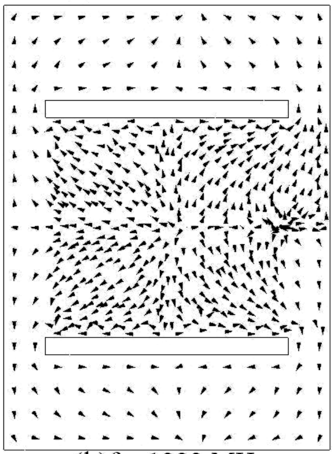


Fig. 2 Resonance curve plot for (a) E-shaped MSA gap-coupled to RMSAs and (b) isolated parasitic pair of rectangular slot cut RMSA, (—) l_s = 0, (— —) l_s = 5.0, (— – —) l_s = 6, (- - -) l_s = 7, (— – – —) l_s = 8

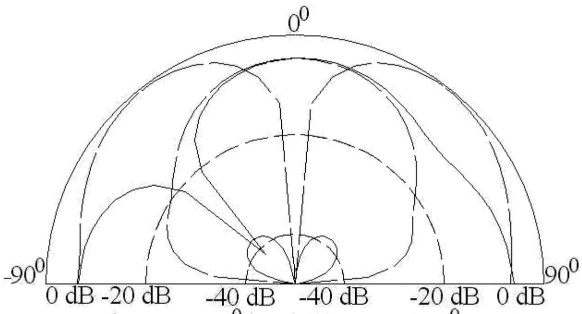
The resonance curve plots for the gap-coupled configuration of these slot cut parasitic RMSAs with proximity fed E-shaped MSA is shown in Fig. 4(a). With an increase in l_s, the TM_{02} mode frequency in parasitic RMSAs comes closer to frequencies of E-shaped patch and TM_{10} mode frequency in parasitic RMSA. For l_s = 8.2 cm, the frequency is close enough so that four loops are formed in the input impedance locus as shown in Fig. 4(b). The resonance curve for the same is shown in Fig. 4(c). All the four loops are not completely inside the VSWR = 2 circle. To optimize them, patch width of E-shaped MSA is reduced. The resonance curve plots for this reduced width are shown in Fig. 4(c). With the reduction in patch width, two mode frequencies of the E-shaped patch are increased (as shown by arrows). Also the impedance at them is modified such that peaks in the resonance curve of gap-coupled proximity fed E-shaped MSA with parasitic rectangular slot cut RMSA are closer to each other that results in formation of four loops inside the VSWR = 2 circle as shown in Fig. 4(d).



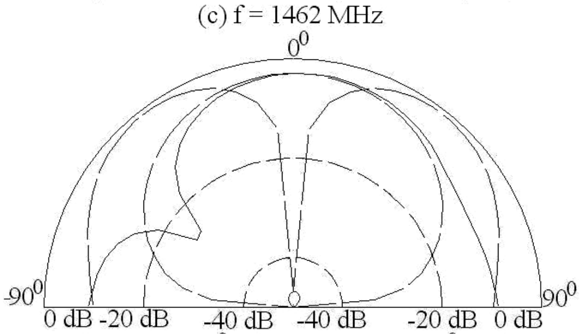
(a) f = 1462 MHz



(b) f = 1222 MHz

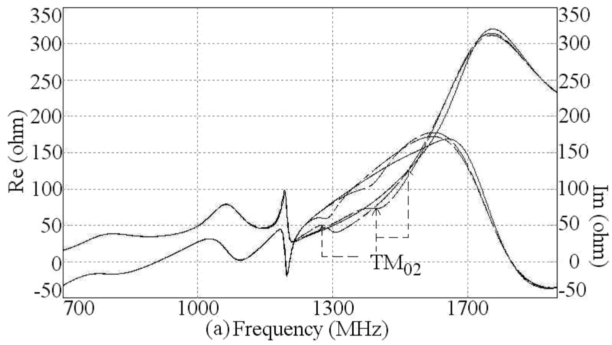


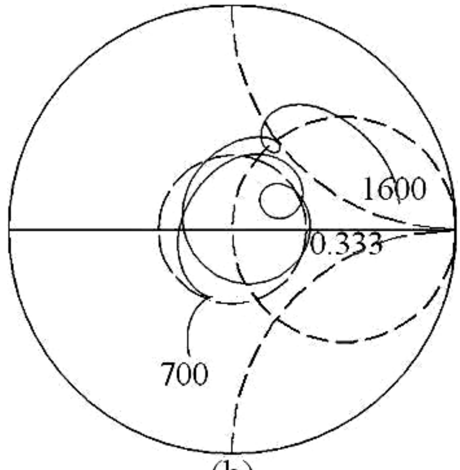
E-plane, Φ=90⁰(——),H-plane,Φ=0⁰(– –)
(c) f = 1462 MHz



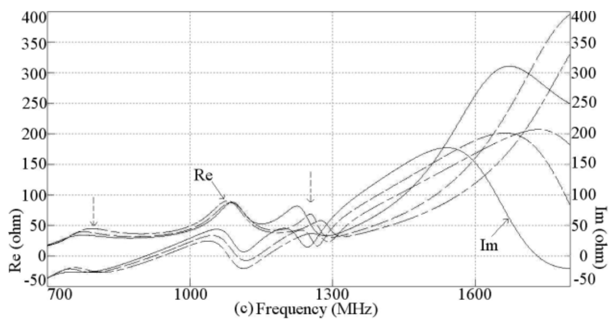
E-plane, Φ=0⁰(——),H-plane,Φ=90⁰(– –)
(d) f = 1222 MHz

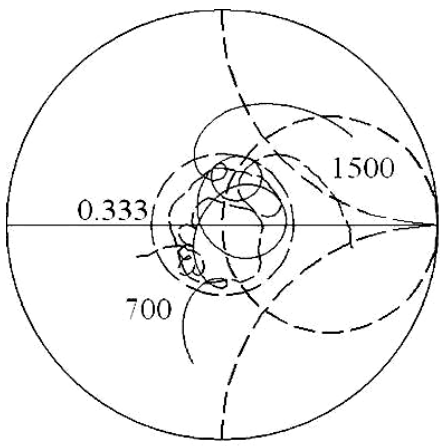
Fig. 3 (a – d) Surface current distribution and radiation pattern plots at TM_{02} mode for l_s = 0 and 8 cm





(b)





(d)

Fig. 4 (a) Resonance curve plot (—) l_s = 5, (— —) l_s = 7.0, (— – —) l_s = 8 and (b) input impedance plot for E-shaped MSA gap-coupled to slot cut RMSAs, its (c) resonance curve plots for varying patch widths, (—) 15 cm, (– –) 12.5 cm, (— – —) 10 cm, and its (d) optimized input impedance plots, (—) simulated, (— —) measured

4. CONCLUSIONs

Broadband proximity fed E-shaped MSA and its gap-coupled configuration with pair of rectangular slot cut RMSAs is discussed. An analysis of gap-coupled slot cut configuration for variations in slot length is proposed. The isolated parasitic RMSA in the gap-coupled configuration is also separately studied for variation in slot length. It was observed that the slot reduces the resonance frequency of higher order orthogonal TM_{02} mode of parasitic RMSA and along with the modes of E-shaped MSAs realizes broadband response. To further optimize the BW, patch width in E-shaped MSA is decreased, which realizes the tuning of E-shaped patch frequencies with that of the parasitic RMSA frequencies. The slot cut gap-coupled configuration shows higher cross-polar levels towards the higher frequencies of BW. This is due to the vertical surface current components inside the parasitic slot cut RMSAs. The proposed study will help in understanding the functioning of broadband slot cut gap-coupled configurations.

5. REFERENCES

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